EFFECTS OF WATERSHED ALTERATION ON THE BROOK TROUT POPULATION OF A SMALL BLACK HILLS STREAM

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ABSTRACT.—The impacts of adjacent landscaping activity and livestock presence on the brook trout (*Salvelinus fontinalis*) population of a small Black Hills stream were evaluated. Moderate changes in temperature, turbidity, and fecal coliform numbers did not influence brook trout densities. Stream morphometry, particularly factors affecting stream cover, appeared to have the greatest impact on numbers of trout. Brook trout were poor indicators of moderate changes in water quality, but they were adequate indicators of the physical perturbations within the stream.

The aquatic biota of streams within the forests of our nation are being increasingly stressed by logging, livestock grazing, mining, road construction, and residential development. Impacts of these activities on streams are often manifested by changes in water quality or through physical changes in the habitat, such as channel modification or reduction in stream flow. Such environmental changes can produce biological responses that alter composition and abundance of resident species. Organisms sensitive to environmental change function as indicators of environmental modification and may be useful in evaluating the magnitude of an impact.

Not all aquatic organisms exhibit equal sensitivity to the same stresses, however. Aquatic invertebrates are sensitive to water quality changes resulting from organic enrichment (Hilsenhoff 1977, Jones et al. 1981) and toxic pollutants (Hocutt 1975) but are not always effective in evaluating moderate physical modifications (Marsh and Waters 1980). Conversely, because of their mobility, Price (1979) suggested that fishes may not be reliable indicators of change in water quality, although fish frequencies do respond to changes in structure of the habitat (Platts 1974, Binns and Eiserman 1979).

The objective of this study was to evaluate the response of a resident brook trout (*Salvelinus fontinalis*) population to water quality and habitat changes in a small Black Hills stream subjected to landscaping activities (clearcutting an adjacent slope and pond dredging) and intermittent livestock grazing within the watershed.

METHODS

The study area included five sampling stations within the upper Slate Creek watershed (Fig. 1) in Pennington County, South Dakota. Two stations were established above a development site within the watershed, one on South Slate Creek and the other on Slate Creek proper, both first order streams. A third sampling station was located 0.1 km downstream from the development site on Slate Creek; two additional stations were established downstream at approximately 1.0 km intervals. Stations above the construction site were not exposed to grazing except for a confined watering site above station 1, whereas stations below the construction site were exposed to grazing during the late fall and winter months.

Twelve water quality variables were measured at three-week intervals during the spring and summer of 1981 and 1982. During the period between August 1981 and April 1982, water samples were collected at intervals ranging between six and eight weeks. Total hardness, alkalinity, dissolved oxygen, pH, and conductivity were determined onsite with field analysis units. Turbidity, total phosphorus (ortho and total), nitrogen (Kjeldahl and ammonia), and fecal coliform bacteria were determined in the laboratory.

Fishes were collected from each station by electrofishing a 61 m section of stream blocked from both directions by 6.4 mm mesh seines. Population estimates were repre-

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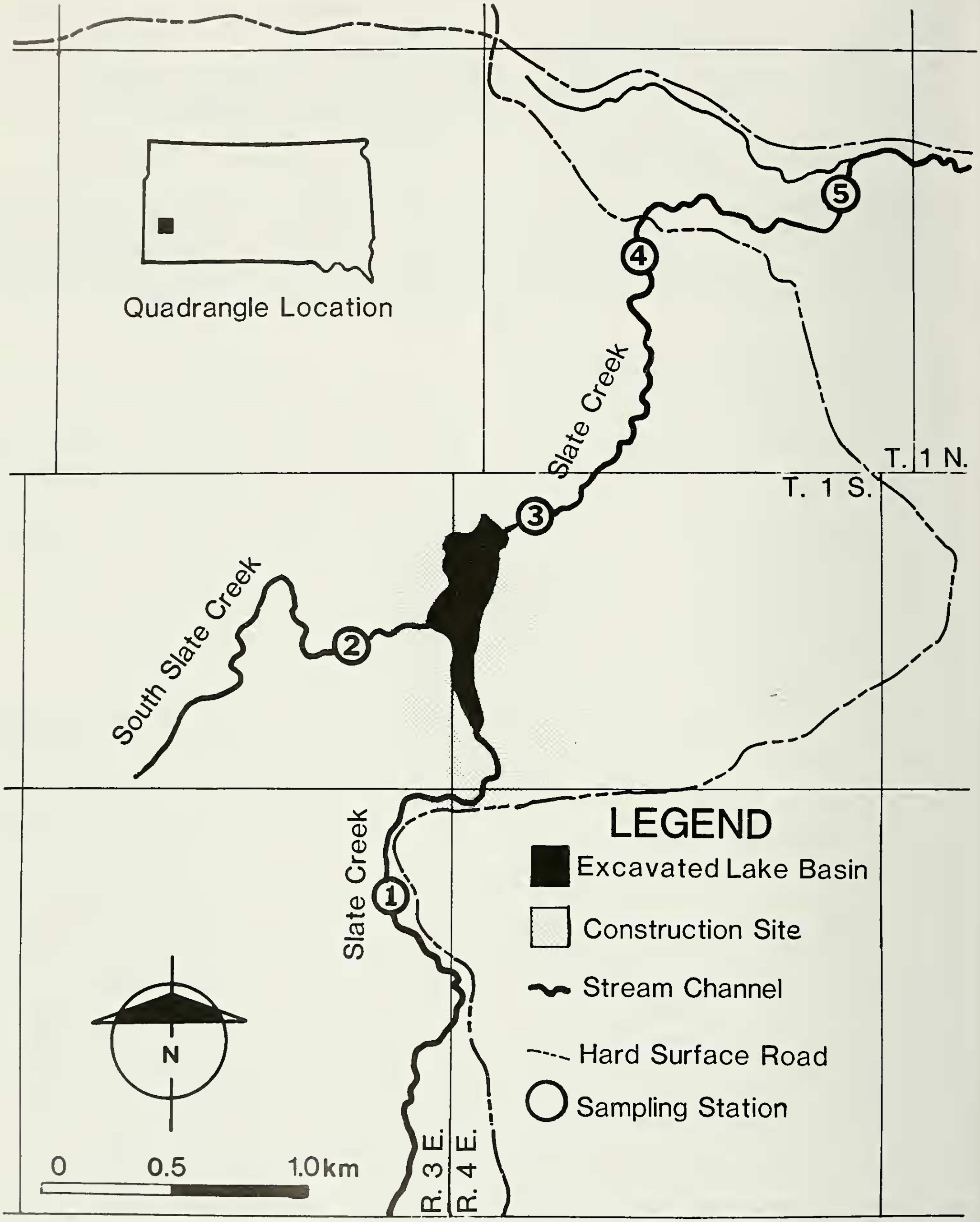

Fig. 1. Map indicating location of the five sampling stations in relation to the Deerfield Park development site in Pennington County, South Dakota.

sented by the total number of fish collected in two consecutive electroshocking passes. Length and weight of brook trout were recorded and scale samples taken during each collection. Fish were sampled at approximately six-week intervals between 9 June 1981 and 29 August 1981 and between 24 May 1982 and 12 August 1982. Because of the absence of flow from the electroshocking site at station 2 during 1981, no fish were collected that year. Fish collected from each station on 24 May 1982 were marked with a subcutaneous latex injection to evaluate movement within the stream. Age was determined by analysis of scale annuli. Relative weights (W_r) (Anderson 1980) were computed using standard weights proposed by Cooper (1961).

Stream morphometry characteristics were measured in July 1982 at each of the five electrofishing stations. Eleven transects perpendicular to the stream bank and spaced 6.1 m apart along each 61-m section of stream were established. Stream width and water depth at 0.15-m intervals across the transect and at both banks were measured. Data from the 11 transects were pooled, and mean depth, width, and depth at stream-bank interface were calculated. Percent of stream canopy coverage at each transect was estimated by assigning numerical values from 1 to 5 corresponding to intervals of stream canopy cover (1 = 81%–100%, 2 = 61%–80%, 3 = 41%–60%, 4 = 21%–40%, 5 = 0%–20%) which shaded the stream surface. Bottom substrate at each station was also examined. A shovel was used to remove three samples of substrate at each station. Samples were air dried, weighed, and sifted through a series of USA Standard Testing sieves. Mean percent by weight of rubble (>76.2/mm), medium/coarse gravel (4.7–76.2/mm), fine gravel (2.0–4.7/mm), coarse sand (1.0–2.0/mm), medium sand (0.5–1.2/mm), and fine sand/silt (<0.5/mm) was calculated for each station.

Analysis of variance was utilized to test for differences in brook trout relative density (number of fishes per 61 m of stream), relative weight (among stations, month, and year), and stream morphometry measurements (among stations). Because the number of brook trout collected at many stations was small, these data were transformed by adding 0.5 to the mean for each station for each date and the square root derived. Following analysis, the transformed data were then squared for presentation of results. Waller-Duncan's K-ratio t-test was employed to define differences. Differences were considered significant at $P \leq 0.05$.

RESULTS

Twelve physicochemical parameters were evaluated on 16 dates from each of the five sampling stations. Variation in precipitation between 1981 and 1984 (Fig. 2) affected water quality between years. Based upon long-term averages from Lead and Spearfish, precipitation in the Black Hills was above normal in 1982, whereas 1981 was a year of lower than normal precipitation. Increased runoff resulted in elevated stream flows throughout the summer of 1982. Mean values for dissolved oxygen and organic phosphorus were significantly higher in 1982 and mean conductivity and pH were significantly lower. Mean fecal coliform number, ammonia nitrogen, and total (Kjeldahl) nitrogen values were higher from all stations in 1982, but these differences were not significant.

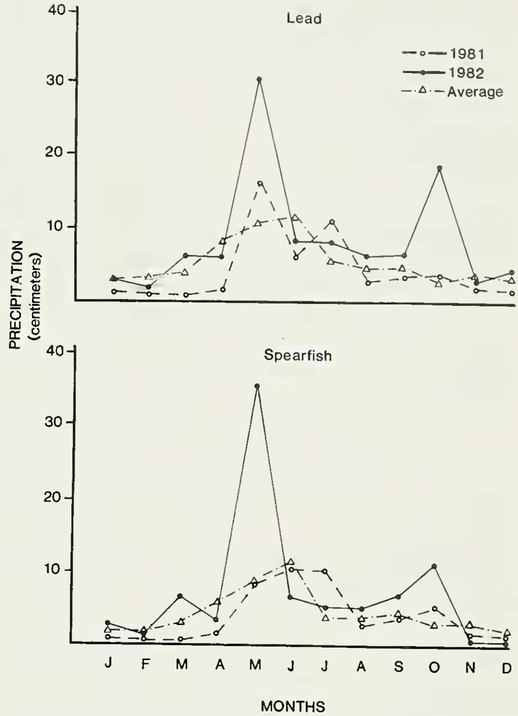

Fig. 2. Monthly precipitation levels for the Lead and Spearfish, South Dakota, gauging stations in the Black Hills during 1981 and 1982.

Seven physicochemical variables differed significantly among stations. Mean turbidity was significantly higher at stations 3, 4, and 5 than upstream at stations 1 and 2 (Table 1). The highest mean turbidity value was at station 3 (35.7 ntu) just below the development site. Mean temperatures at stations 3 and 4 were significantly higher than upstream of stations 1 and 2. Temperature decreased signifi-

TABLE 1. Means of water quality parameters among five stations on Slate Creek.[1]

Variable (Units of measure)	Station 1	2	3	4	5
Turbidity (NTU)	7.1[a]	3.9[a]	35.7[b]	28.4[b]	26.9[b]
Temperature (C)	10.1[a]	9.1[a]	12.5[b]	11.5[b,c]	10.4[a,c]
pH	7.5[a]	7.1[b]	7.4[a]	7.5[a]	7.3[a]
Conductivity (μmhos)	161.0[a]	115.4[b]	163.3[a]	163.2[a]	167.6[a]
Hardness (mg/l $CaCO^3$)	110.3[a]	82.5[c]	102.5[b]	105.3[a,b]	105.0[a,b]
Alkalinity (mg/l $CaCO^3$)	101.2[a]	81.9[b]	94.1[a]	97.8[a]	100.0[a]
Fecal coliform (#/100ml)	173.7[a,b]	78.8[b]	100.2[b]	163.9[a,b]	309.4[a]

[1]Means followed by the same superscript for each variable are not different ($P > 0.05$) based on Waller Duncan's K-ratio t-test.

TABLE 2. Numbers and species of fishes collected from Slate Creek and South Slate Creek between June 1981 and August 1982.

	1981				1982			
	June	July	August	$\bar{X}$	May	July	August	$\bar{X}$
Station 1								
Brook Trout	5	2	1	2.7	8	12	6	8.7
White sucker	0	1	0	0.3	0	0	0	0.0
Longnose dace	0	0	0	0.0	0	0	0	0.0
Fathead minnow	0	0	0	0.0	0	0	0	0.0
Station 2								
Brook trout	0	0	0	0.0	5	8	5	6.0
White sucker	0	0	0	0.0	0	0	0	0.0
Longnose dace	0	0	0	0.0	3	0	2	1.7
Fathead minnow	0	0	0	0.0	0	0	0	0.0
Station 3								
Brook trout	7	4	4	5.0	5	5	2	4.0
White sucker	1	2	2	1.3	0	5	1	2.0
Longnose dace	1	2	5	2.7	2	23	23	16.0
Fathead minnow	0	0	0	0.0	0	1	0	0.3
Station 4								
Brook trout	15	44	26	28.3	9	14	19	14.0
White sucker	0	0	0	0.0	0	5	5	3.3
Longnose dace	6	7	2	5.0	1	1	7	3.0
Fathead minnow	0	0	0	0.0	0	0	0	0.0
Station 5								
Brook trout	19	8	20	15.7	12	12	11	11.7
White sucker	7	2	0	3.0	0	10	21	10.3
Longnose dace	14	21	53	29.0	0	6	10	5.3
Fathead minnow	0	0	0	0.0	0	0	0	0.0

cantly from a mean of 12.5 C at station 3 to 10.4 C downstream at station 5. Mean temperature at station 5 was not significantly different from mean values from stations 1 and 2. Conductivity, pH, hardness, and alkalinity were all significantly lower at station 2 than at any of the other stations. Mean total coliform numbers at station 5 were significantly higher than at stations 2 and 3. No significant differences were detected among the five stations for phosphorus (orthophosphate and organic phosphate) or nitrogen (ammonia and organic), but nutrient levels were the highest at stations 4 and 5.

Brook trout, an introduced game species, was the most abundant fish in the study area and was the only species consistently collected at stations both above and below the development site (Table 2). Brook trout composed 53.4% of the fishes collected from the five stations over the two-year period. Other species occurring within the study area were white sucker (*Catostomus commersoni*) (11.3%), longnose dace (*Rhinichthys cataractae*) (35.1%), and fathead minnow (*Pime-phales promelas*) (0.2%).

Differences among stations were observed during both years of the study. Significant dif-

TABLE 3. Mean densities of brook trout per 61m of stream from five stations along Slate Creek during 1981 and 1982.[1]

	Station Number				
Year	1	2	3	4	5
1981	3.0[a]	0.5[a]	5.4[a,b]	28.6[c]	15.6[b,c]
1982	9.0[a]	6.4[a]	4.4[a]	14.2[b]	12.2[a,b]

[1]Means followed by the same superscript across rows are not different (P > 0.05) from each other based on Waller Duncan's K-ratio t-test.

TABLE 4. Mean values for stream morphometry characteristics among five stations along Slate Creek.[1]

Variable	Station				
(Units of measure)	1	2	3	4	5
Stream depth (cm)	12.2[a]	27.9[b]	14.8[a]	24.7[b]	28.1[b]
Stream-shore depth (cm)	5.5[a]	11.4[a,b]	5.0[a]	19.0[b,c]	23.1[c]
Stream cover (%)	3.6[a]	5.0[b]	3.6[a]	1.8[c]	3.4[a]
Fine sand/silt (%)	2.6[a]	0.7[a]	29.6[b]	11.6[a,c]	22.6[b,c]
Stream width (cm)	93.3[a,c]	260.7[b]	94.0[a,c]	67.7[a,c]	106.7[c]

[1]Means followed by the same superscript for a variable are not different (P > 0.05) from each other based on Waller Duncan's K-ratio t-test.

ferences ($P \leq 0.05$) were observed both among stations and station-year interaction. Due to the interaction observed, data from each year was subjected to a separate analysis of variance. The results indicated that during 1981, fish were most abundant in downstream stations (i.e., 4 and 5). A weaker trend among stations in trout density was observed during 1982, although the highest numbers of brook trout were still collected in the downstream stations (Table 3).

Increases in trout density were generally consistent with increases in mean stream depth and mean depth at the bank (Table 4). During both years brook trout densities below the development site were higher at station 4, which had the greatest summer canopy cover and the lowest amount of sand or silt deposition among downstream stations. Significant differences in stream width among stations did not appear to be related to trout density. Although mean bank depth and mean depth of stream were high at station 2, trout densities were low because flows were not perennial through the 61 m electrofishing section.

Considerable variation in brook trout (relative weight) W_r was observed during the study (Fig. 3). During 1981, when stream flows were low, mean W_r decreased from 95.0 in early June to 79.7 in late August. However, in 1982, when stream flows were higher, W_r declined little during the summer months. Analysis of variance indicated significant ($P < 0.05$) differences in W_r among years, months, and stations. The highest mean W_r values were observed at station 2; the lowest were at station 4.

The brook trout population of Slate Creek consisted primarily of age-class I and II fish; age-class III fish were collected only in 1982 (Fig. 4). The 1980 year-class was the strongest cohort during both years of the study. Recruitment within the study area occurred primarily at station 4 and, to a lesser extent, at station 3. During both years of the study, the numbers of young-of-the-year fish collected were lower than the number of yearlings. Age-class I fish composed that largest portion of that Slate Creek brook trout population at all stations during the study, and were always dominant at stations 1 and 2. No movement of brook trout was observed among stations. Mean recapture rates of fish marked in late May were 41.0% on 1 July and 12.8% on 12 August 1982.

DISCUSSION

Lotic populations of brook trout are typified by short-lived populations (McAfee 1965) inhabiting headwater streams (Neves and Pardue 1983). Brook trout exhibit a high tolerance to environmental variation. Lee and Rinne (1980) observed brook trout, a char, to have a slightly higher tolerance to elevated temperature fluctuation than several other trout species, and Brett (1956) reported that brook trout have a greater cold tolerance than several trout species. In addition, brook trout are also tolerant to extremes to both pH (Daye and Garside 1975) and turbidity (Gradall and Swenson 1982). Tolerance to environmental

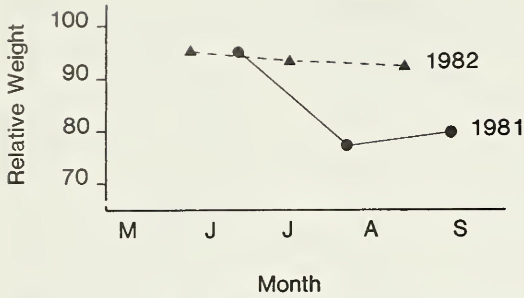

Fig. 3. Mean relative weight (W_r) values for brook trout by month from Slate Creek and South Slate Creek for 1981 and 1982.

change has no doubt led to the success of brook trout stocking within a wide geographical range outside its native distribution (MacCrimmon and Campbell 1969).

Tolerance to changes in water quality results in low sensitivity to some forms of environmental perturbation. In the present study, brook trout were poor indicators of the observed changes in turbidity, temperature, and nutrient loading. Natural fish populations have been considered inferior to macroinvertebrate communities as water quality indicators even though individual fish species have been successfully utilized in bioassays (Price 1979). However, several researchers (e.g., Binns and Eiserman 1979, Raleigh 1982, Parsons et al. 1981) have studied the importance of physical characteristics of streams in determining trout density. Brook trout densities in the present study were responsive to changes in physical characteristics of the stream, particularly stream flow, mean stream depth, depth at the bank, and canopy cover—the major components of cover in a small stream. Both Stewart (1970) and Hunt (1971) similarly reported that depth and cover were dominant factors affecting brook trout densities in streams. Fraley and Graham (1981) observed that cover, substrate, and depth were the primary factors among 30 physical habitat characteristics measured that best predicted densities of cutthroat trout (*Salmo clarki lewisi*) and bull trout (*Salvelinus confluentus*).

Relative weights were higher for brook trout during 1982, when high precipitation resulted in a greater quantity of drift organisms available (Drewes 1984). The relationship of W_r to stations was probably due to intraspecific competition, with the lowest values occurring at the station with the highest relative density of trout. Condition of trout, as expressed by W_r, was also influenced more by natural variation than water quality.

As primary components of the ichthyofauna in headwater mountain streams, brook trout represent one of the initial biotic components impacted by nonpoint sources of watershed disruption. Because of their tolerance to changes in the water medium, brook trout are not good indicators of moderate alterations in water quality. Brook trout appear to be sensitive to changes in stream morphometry and should be adequate indicators of physical disruptions within streams.

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LITERATURE CITED

ANDERSON, R. O. 1980. Proportional stock density (PSD) and relative weight (W_r): interpretive indices for fish populations and communities. Pages 17–33 *in* S. Gloss and B. Shupp, eds., Practical fisheries management: more with less in the 1980s. New York Chapter, Amer. Fish. Soc., Bethesda. Maryland.

BINNS, N. A., AND F. M. EISERMAN. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Amer. Fish. Soc. 108:215–228.

BRETT, J. R. 1956. Some principles in the thermal requirements of fishes. Quar. Rev. of Biol. 31:75–87.

COOPER, E. L. 1961. Growth of wild and hatchery strains of brook trout. Trans. Amer. Fish. Soc. 90:424–438.

DAYE, P. G., AND E. T. GARSIDE. 1975. Lethal levels of pH for brook trout (*Salvelinus fontinalis*). Canadian J. Zool. 53:639–641.

DREWES, H. G. 1984. Factors affecting water quality and macroinvertebrate distribution within a small Black Hills stream. Unpublished thesis, South Dakota State University, Brookings.

FRALEY, J. J., AND P. J. GRAHAM. 1981. Physical habitat, geologic bedrock types and trout densities in the tributaries of the Flathead River Drainage, Montana. Pages 178–185 *in* N. Armatrout, ed., Acquisition and utilization of aquatic habitat inventory information. Amer. Fish. Soc., Bethesda, Maryland.

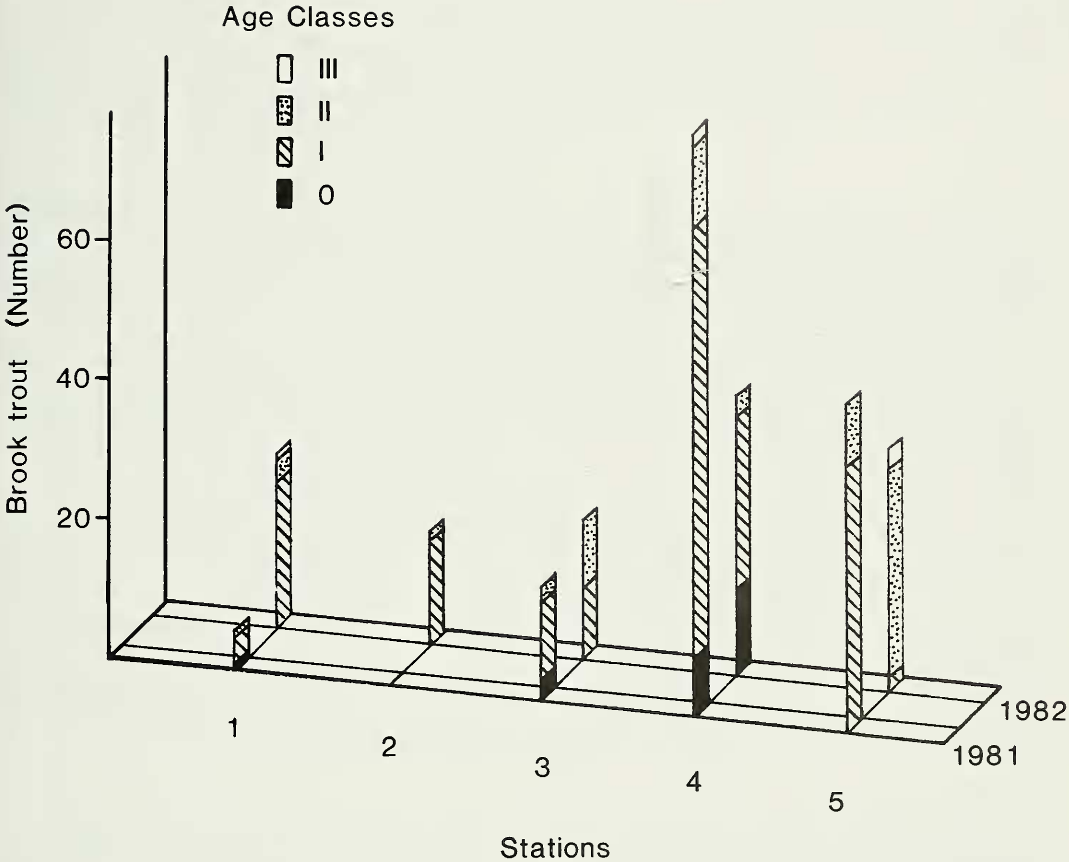

Fig. 4. Age distribution and abundance of brook trout among stations from the Slate Creek study during 1981 and 1982.

GRADALL, K. S., AND W. A. SWENSON. 1982. Responses of brook trout and creek chubs to turbidity. Trans. Amer. Fish. Soc. 111:392–395.

HILSENHOFF, W. L. 1977. Use of arthropods to evaluate water quality of streams. Technical Bulletin 100, Wisconsin Dept. Nat. Res., Madison.

HOCUTT, C. H. 1975. Assessment of a stressed macroinvertebrate community. Water Res. Bull. 11:820–835.

HUNT, R. L. 1971. Responses of a brook trout population to habitat development in Lawrence Creek. Tech. Bull. 48, Wisconsin Dept. Nat. Res., Madison.

JONES, J. R., B. H. TRACY, J. L. SABAUGH, D. H. HAZELWOOD, AND M. M. SMART. 1981. Biotic index tested for ability to assess water quality of Missouri Ozark streams. Trans. Amer. Fish. Soc. 110:627–637.

LEE, R. M., AND J. N. RINNE. 1980. Critical thermal maxima of five trout species in the southwestern United States. Trans. Amer. Fish. Soc. 109:632–635.

MACCRIMMON, H. R., AND J. C. CAMPBELL. 1969. World distribution of brook trout (*Salvelinus fontinalis*). J. Fish. Res. Board of Canada 26:1699–1725.

MCAFEE, W. R. 1965. Eastern brook trout. Pages 242–260 *in* A. Calhoun, ed., Inland fisheries management. California Dept. of Fish and Game, Sacramento.

MARCH, P. C., AND T. F. WATERS. 1980. Effects of agricultural drainage development on benthic invertebrates in undisturbed downstream ranches. Trans. Amer. Fish. Soc. 109:213–223.

NEVES, R. J., AND G. B. PARDUE. 1983. Abundance and production of fishes in a small Appalachian stream. Trans. Amer. Fish. Soc. 112:21–26.

PARSONS, M. G., J. R. MAXWELL, AND D. HELLER. 1981. A predictive fish habitat index model using geomorphic parameters. Pages 85–91 *in* N. Armatrout, ed., Acquisition and utilization of aquatic habitat inventory information. Amer. Fish. Soc., Bethesda, Maryland.

PLATTS, W. S. 1974. Geomorphic and aquatic conditions influencing salmonids and stream classification. U.S. Forest Service, Surf. Environ. and Mining Prog. Rep., Washington, D.C.

PRICE, D. R. H. 1979. Fish as indicators of river water quality. Chapter 8 *in* A. James and L. Evison, eds., Biological indicators of water quality. John Wiley and Sons, New York.

STEWART, P. A. 1970. Physical factors influencing trout density in a small stream. Unpublished dissertation, Colorado State University, Fort Collins.